Photometry and Albedo Maps of Pluto and Charon

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Pluto System after New Horizons
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Summary of Talk

- **Albedo maps: key data set; complements compositional maps, geologic maps, crater counts, and overall view of geologic and exogenic processes**
- **Photometry: yields clues to the nature of surface: roughness; "fluffiness" or compaction of surface; particle size**
- **(Pluto only): nature of atmosphere and hazes, through radiative transfer modeling**

Pluto normal reflectance: extraordinary albedo variegations

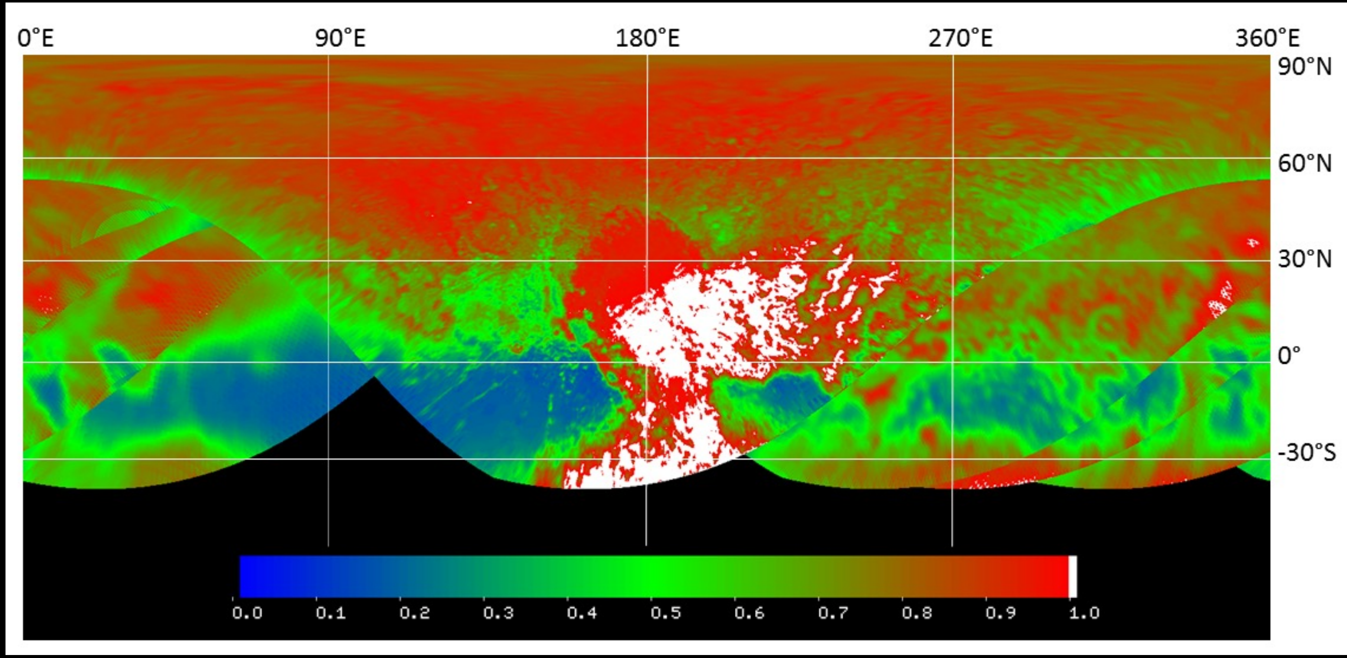
Hints of very high albedo from Earth-based observations:

- Marcialis, 1988 *AJ* (the "two spot model"; "*polar caps with albedos near unity*")

- Stern et al., 1988 *Icarus* "Why is Pluto bright?"

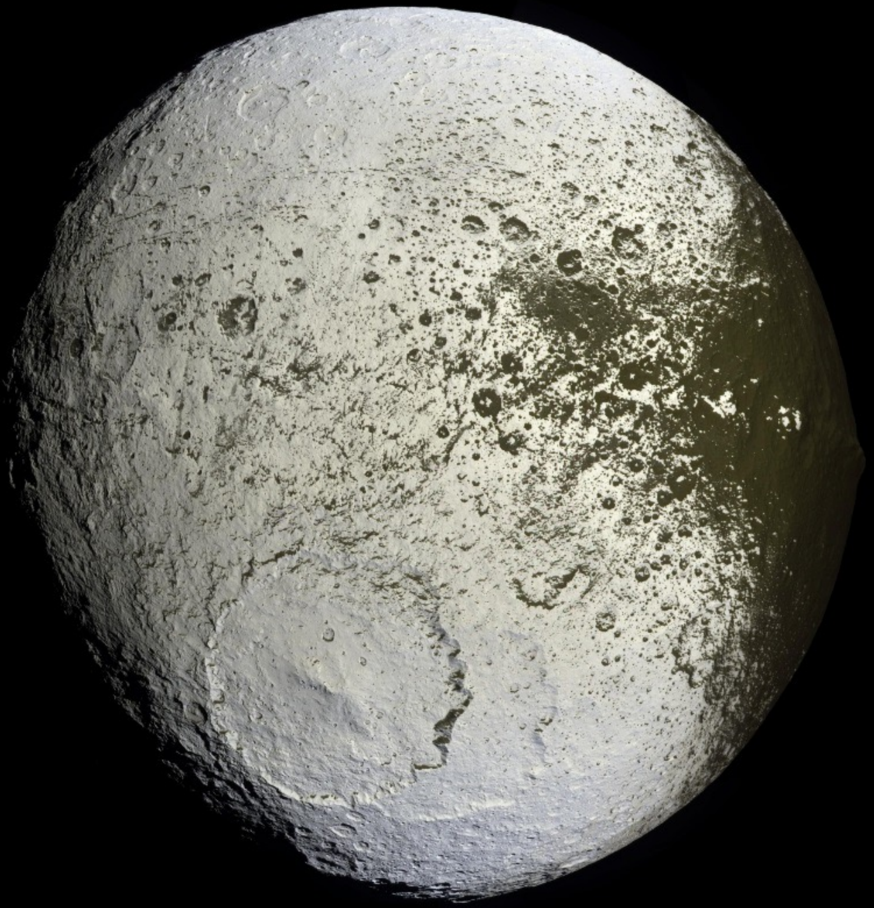
- Young, E. et al. 1999 *AJ* "*This [mutual event] map resolves a localized bright feature that may be due to condensation around a geyser or in a crater.*"

<u>*New Horizons* established a connection between unit albedo and activity</u>

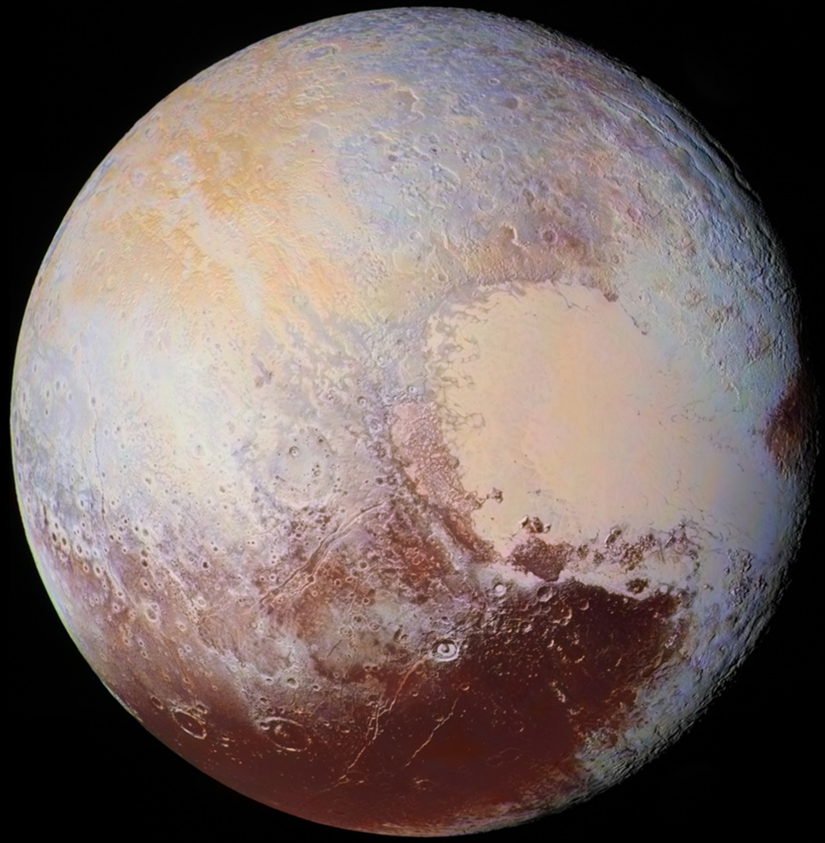


New Horizons map of normal reflectance
Buratti et al., 2017.

Iapetus



Pluto



Pluto: a comparison with other icy bodies

Object	Maximum	Minimum	Source
Pluto	0.95	0.08	This study
Iapetus	0.70	0.02	Buratti et al. 1990
Europa	0.85	0.55 (?)	Buratti&Golombek 1988
Triton	0.90	0.62	McEwen, 1990
Enceladus	1.02	0.96	Buratti et al. 1990*

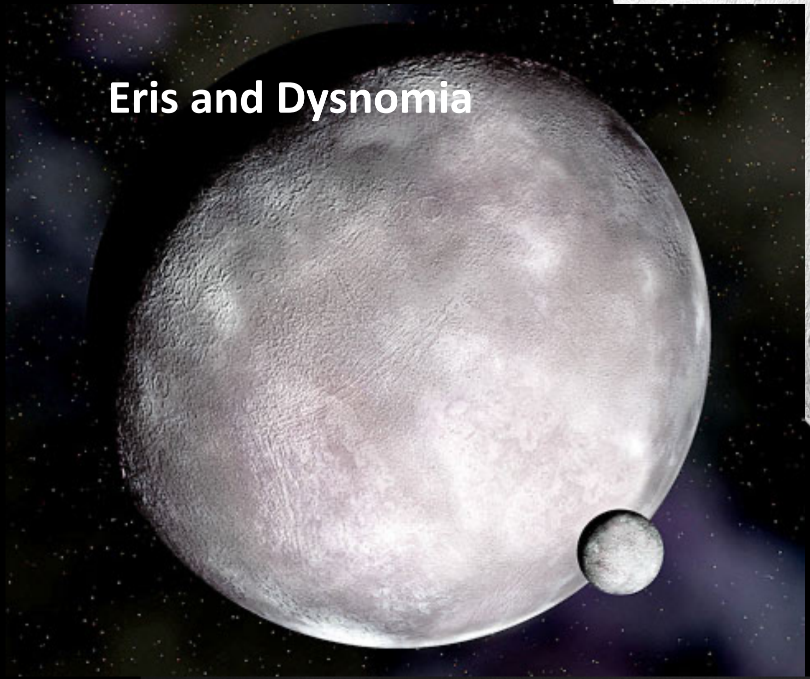
Pluto shows variations as extreme as those of Iapetus, Saturnian moon
Pluto's bright active region is almost as bright as Enceladus

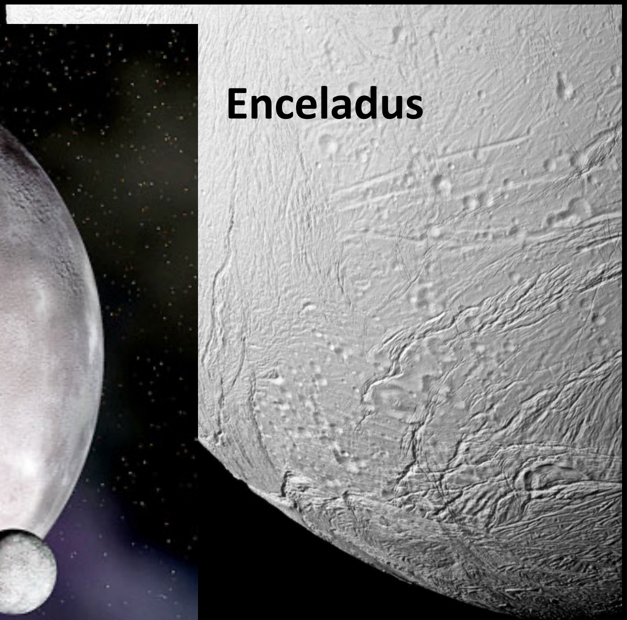
*Albedos at similar geometries were attempted; Verbiscer et al. (2007 report a much higher albedo at opposition).

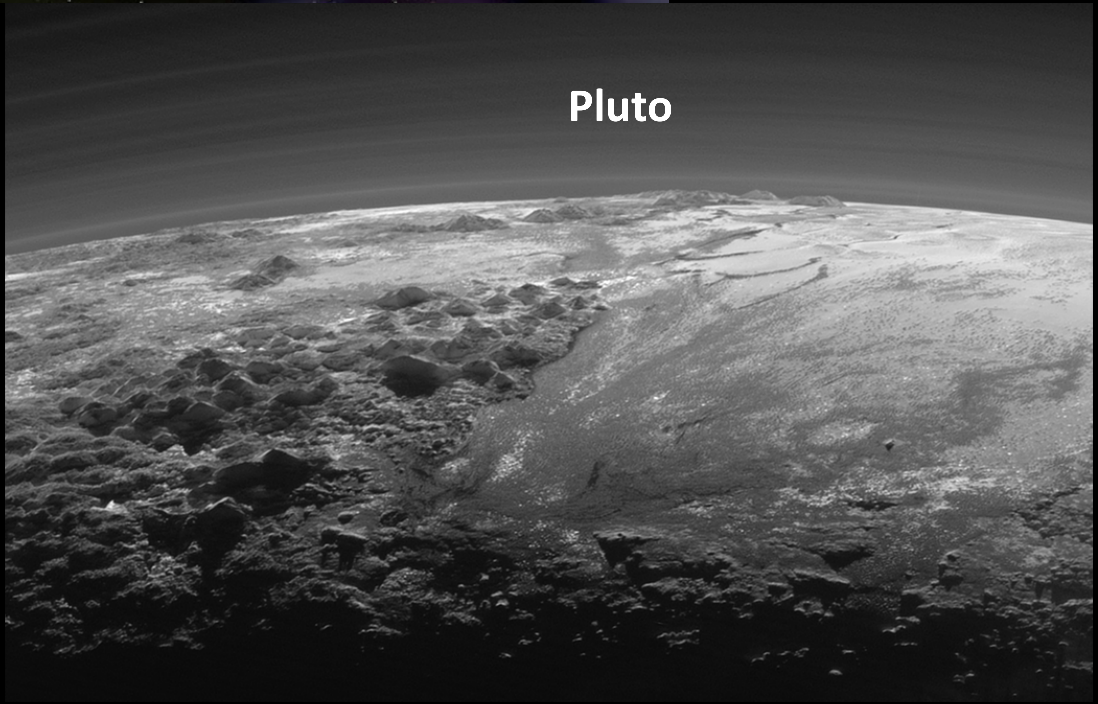
Activity on Eris?

- High albedos near unity have been indicators of activity on planets and moons, such as as is the case for Enceladus (Buratti et al., 1984; Verbiscer et al., 2005, 2007). A possible liquid ocean on Pluto was based on models that computed heating from rock/radioactive isotope fractions. Density of Pluto is 1.9 gm/cc (Stern et al. 2015), and the near-unit albedo on Sputnik Planitia was discovered by *New Horizons* (Buratti et al., 2016).
- The density of Eris is even larger (2.5 gm/cc), and its geometric albedo is 1.0 (Sicardy et al., 2011). These results suggest Eris likely has current cryovolcanic activity on its surface
- Other explanations are possible, such as condensation of CH4 frost without the "tholins" that Pluto has, for example. There is strong evidence against this scenario.:

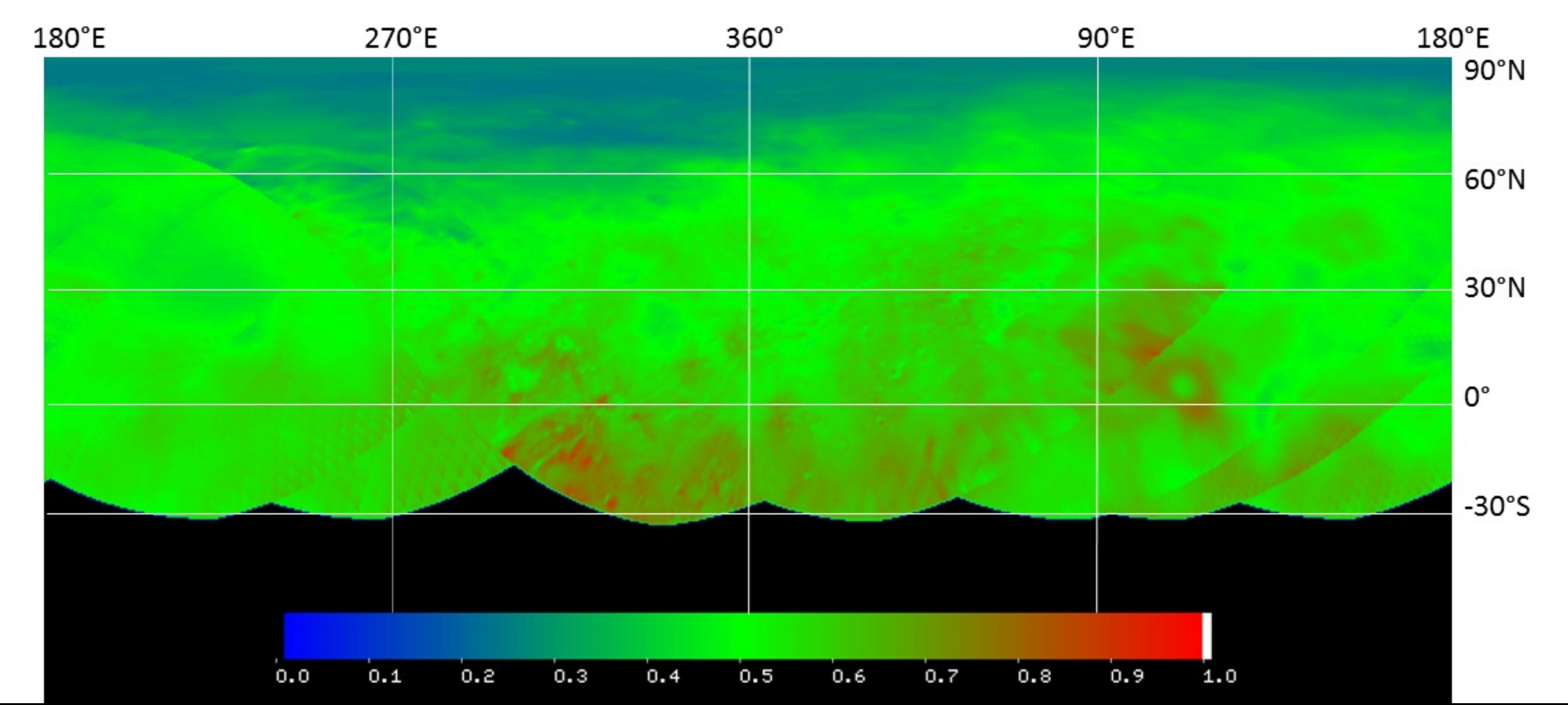
1. The extraordinarily high albedo of Eris and the fact that a small amount of contaminants lowers albedo drastically (Clark et al. 1981)
2. Dust in the Kuiper Belt (Stark, 2011); also may be present on *New Horizons* images
3. The likely presence of hydrocarbons (Simonelli et al., 1989) *ab initio* in Pluto's formation also provides contaminants to the surfaces of KBOs.







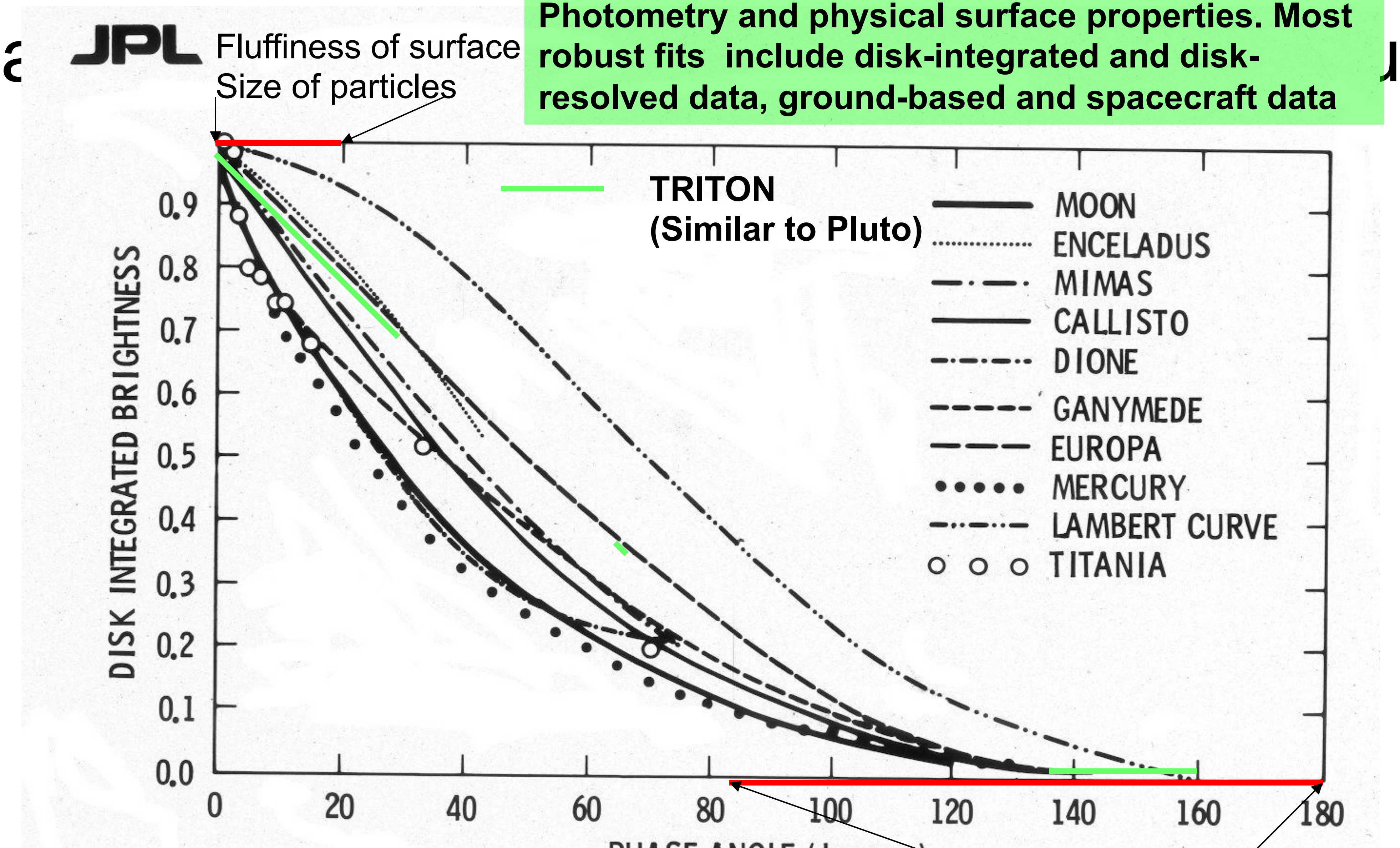
Charon normal reflectance: "normal"



Ba us

Photometry and physical surface properties. Most robust fits include disk-integrated and disk-resolved data, ground-based and spacecraft data

Fluffiness of surface
Size of particles



TRITON
(Similar to Pluto)

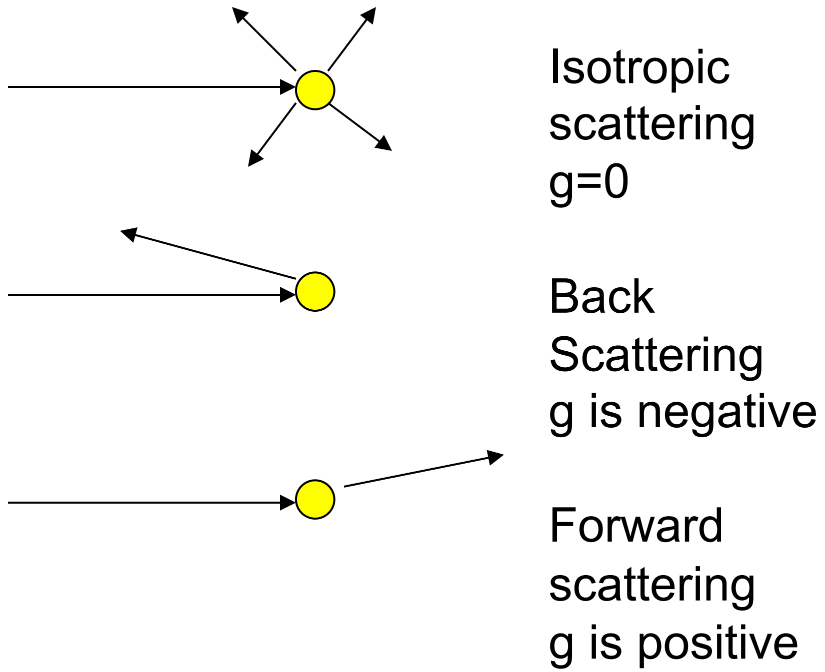
Roughness; size and character of particles

“Opposition”

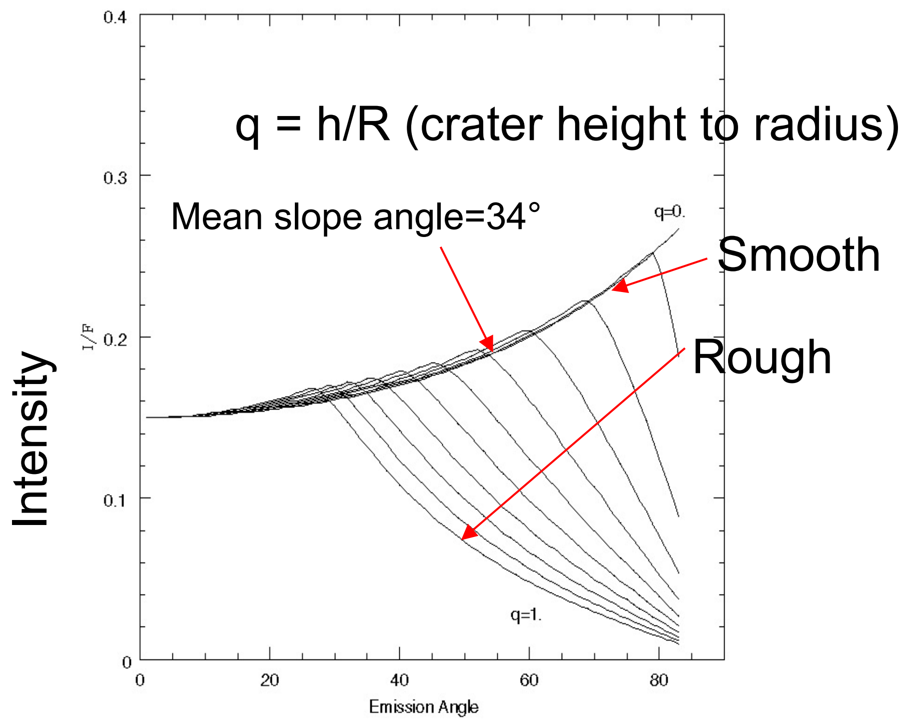
The single scattering albedo and single particle phase function

- The single scattering albedo is the probability a photon will be scattered in any direction after one scattering.
- Single particle phase function gives the specific directional properties and depends on the of the size, shape, and composition of particle
- It is important to obtain observations at large solar phase angles to understand the forward scattering properties of bodies.
- For icy bodies, the solar phase angles observed from Earth are always small; need spacecraft images to determine this parameter.

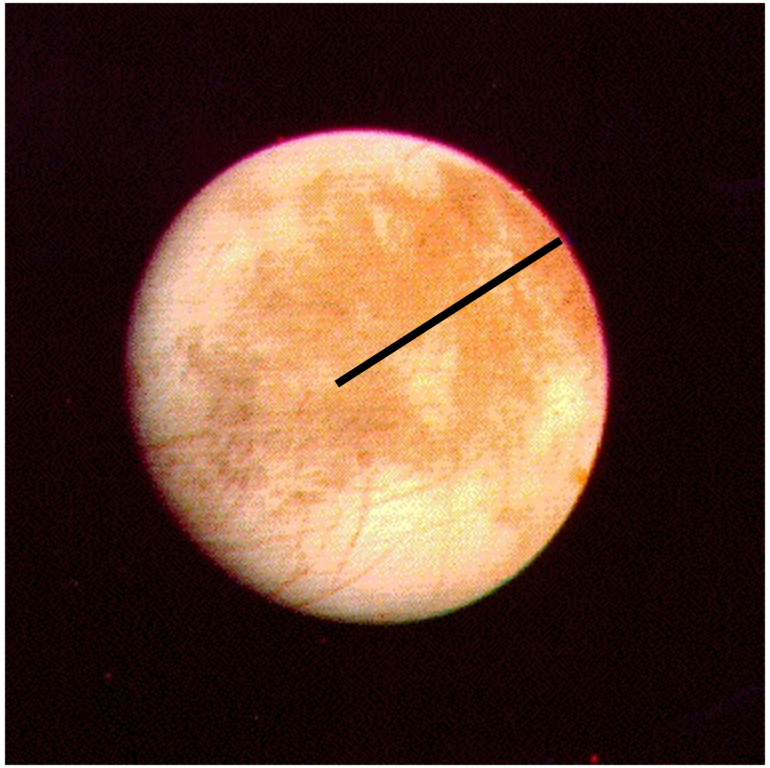
The direction of a photon after a single scattering. An empirical parameter, the Henyey-Greenstein g is often used.



A crater roughness model



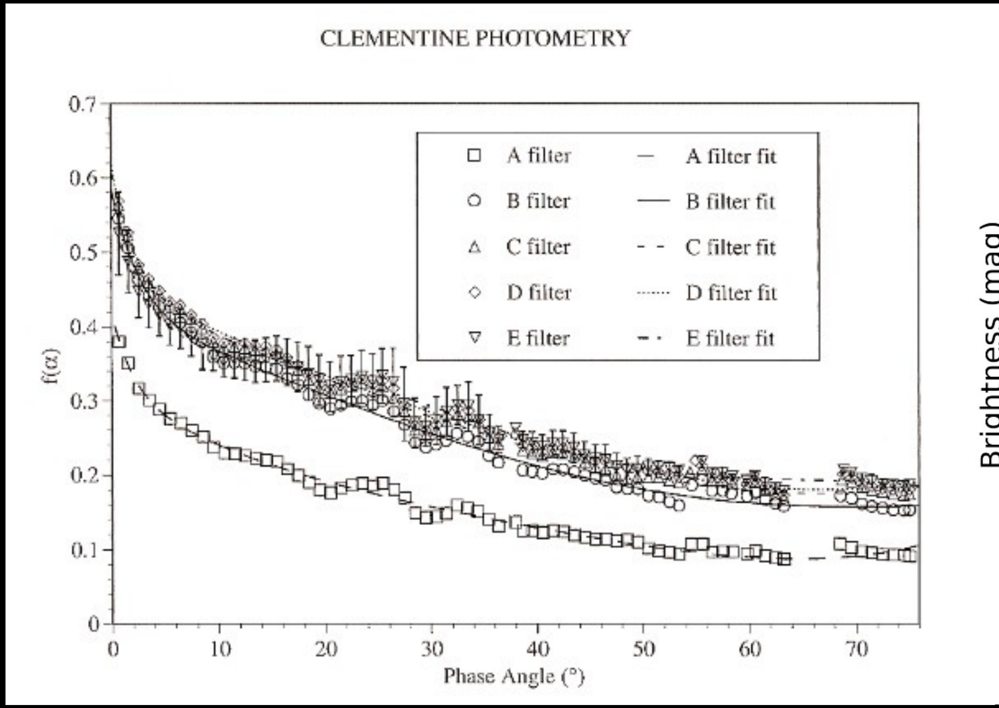
Scan from center to limb



The effects of roughness are most pronounced at large solar phase angles, but disk-resolved data from spacecraft produce the most unambiguous fits.

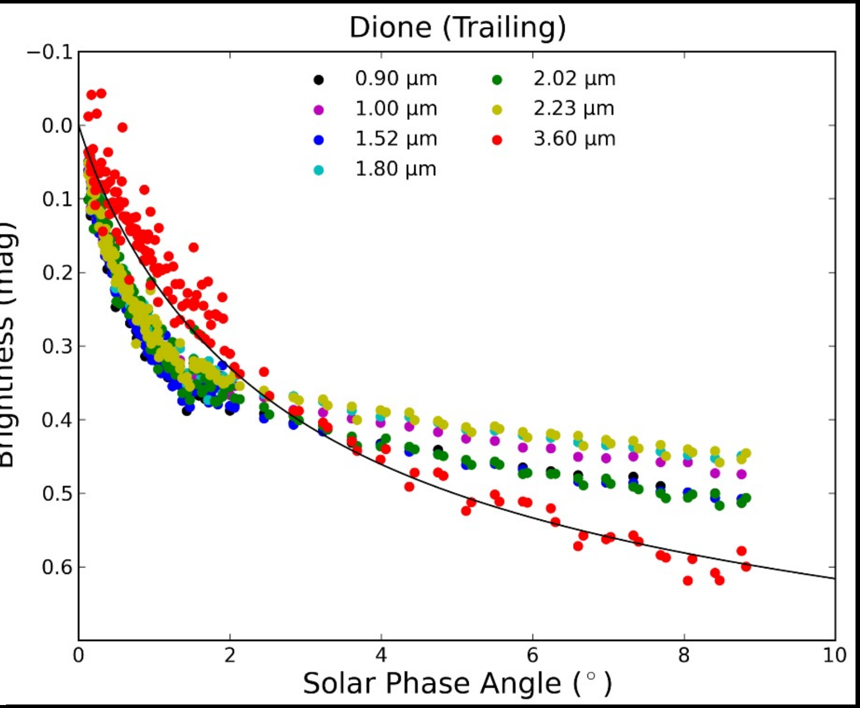
Rocky and icy bodies both exhibit two types of surges

The Moon



Hillier J. et al., 1999

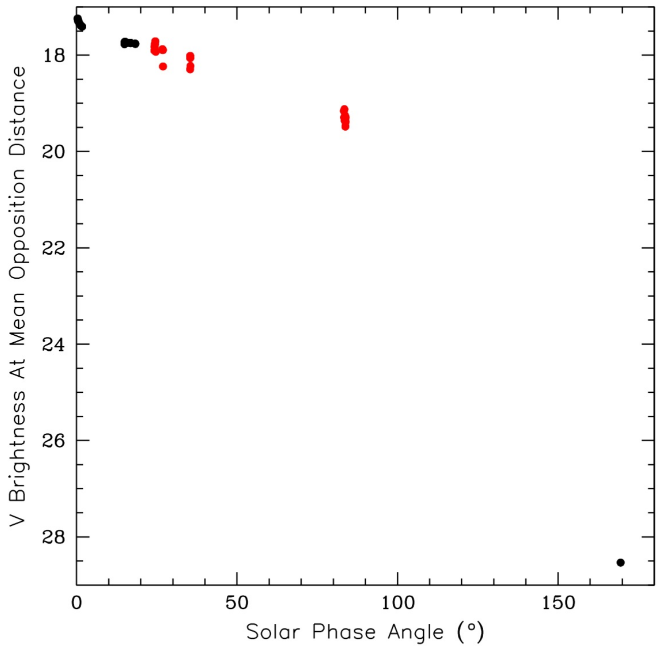
Dione: a typical icy moon

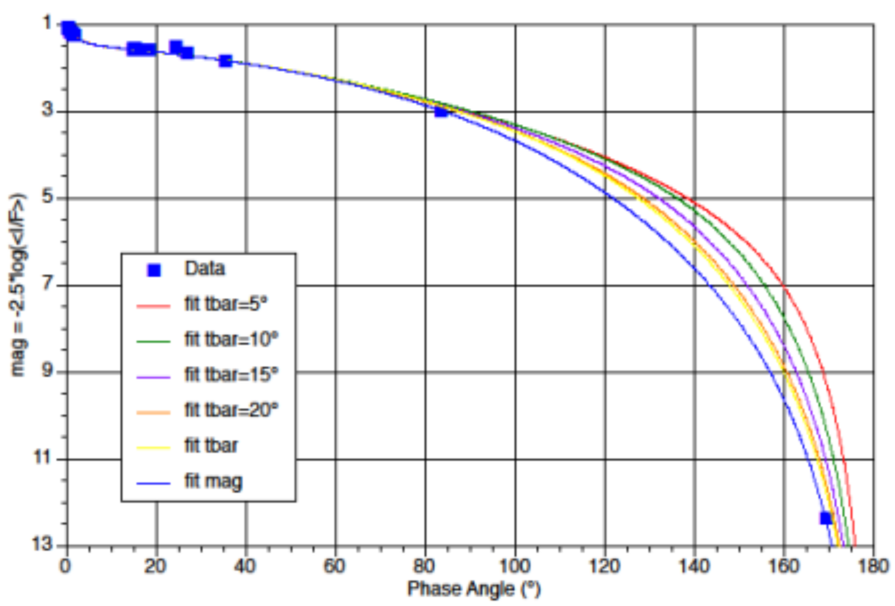


Buratti, B. et al. 2017; Cassini VIMS data

The "supersurge" at very small phase angles is believed to be due to coherent backscatter (Hapke, 1990;1998; 2002). Focus on shadow-hiding………

Charon’s solar phase curve



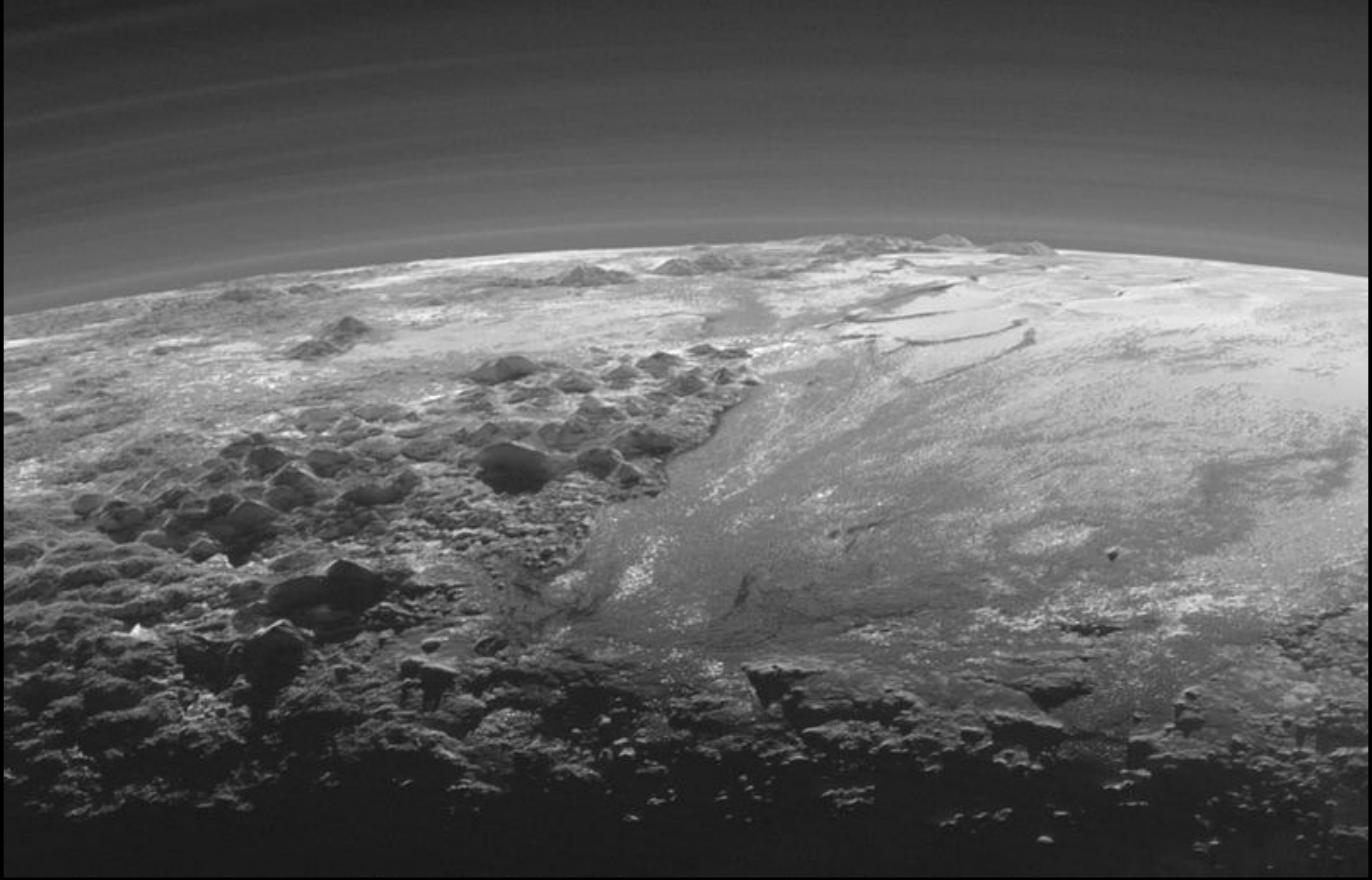


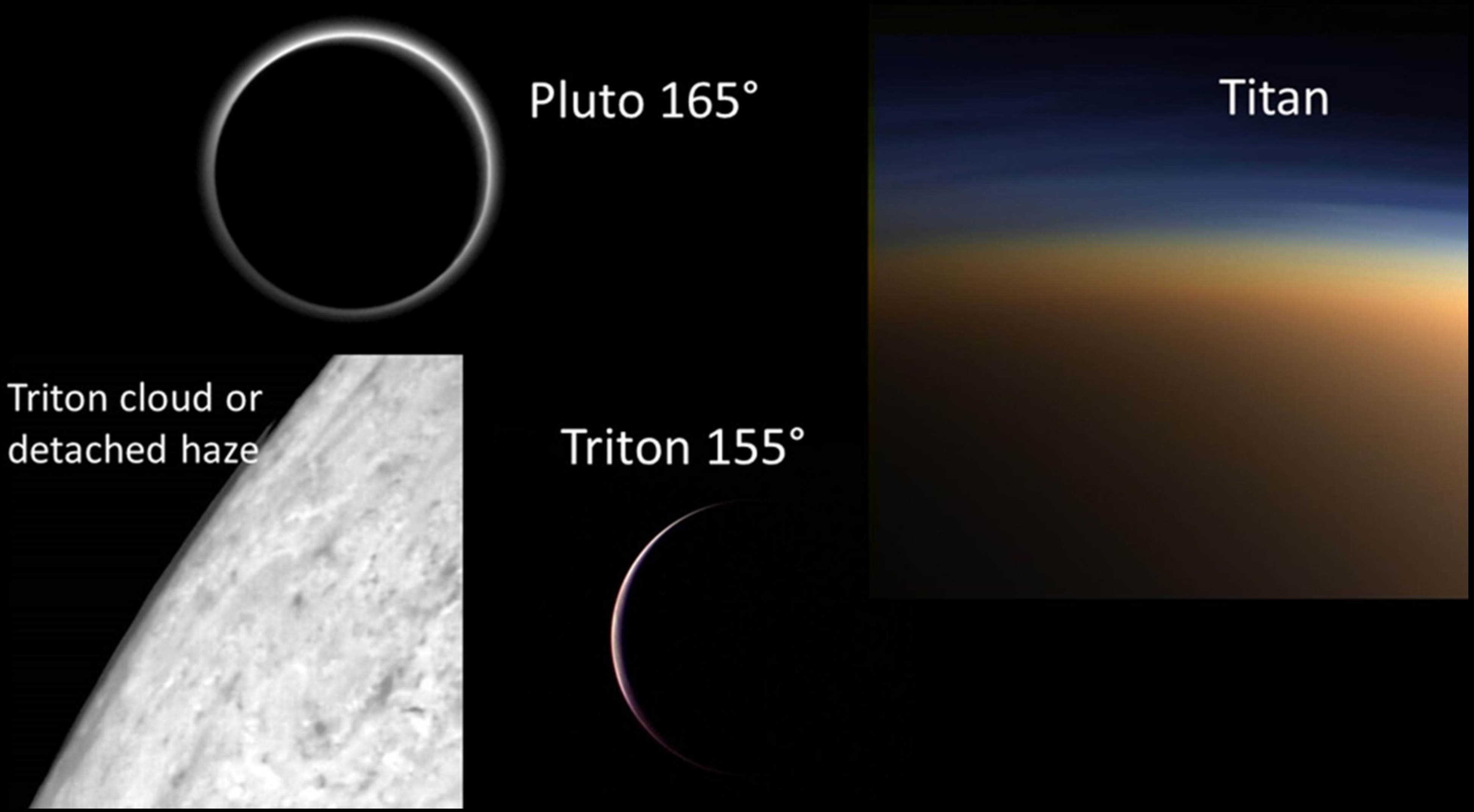
Charon: A comparison

Object	w	g	Slope angle θ(°)	h (s)*	h (c)*	B_o (s)*	B_o (c)*	Source
Charon	0.72	-0.09	23	0.150	0.037	0.001	0.536	This study
Nix	0.86	0.49	20**	0.50	0.019	0.94	0.87	Verbiscer et al., 2018
Hydra	0.95	0.44	20**	0.16	0.0043	0.88	0.45	Verbiscer et al., 2018
Rhea	0.861 0.989	-0.29 0.2	13±5 33	0.08 0.0004		1.37 1.8		Verbiscer and Veverka, 1989 Ciarnello et al., 2011
Europa	0.964	-0.15± 0.04	10	0.0016		0.5		Buratti, 1985; Domingue et al., 1991
C-asteroids	0.037	-0.47	20**	0.025		1.03		Helfenstein and Veverka 1989
S-asteroids	0.23	-0.27	20**	0.08		1.60		Helfenstein and Veverka 1989
Moon	0.25	-0.25	20	0.05		1.0		Buratti 1985; Hillier et al. 1999
Vesta	0.49	-0.23	8	0.076		1.66		Li et al. 2013

*Hapke's later models have separate parameters for the shadow-hiding and coherent backscatter portions of the opposition surge.

**Assumed




Pluto 165°
Titan
Triton cloud or
detached haze
Triton 155°

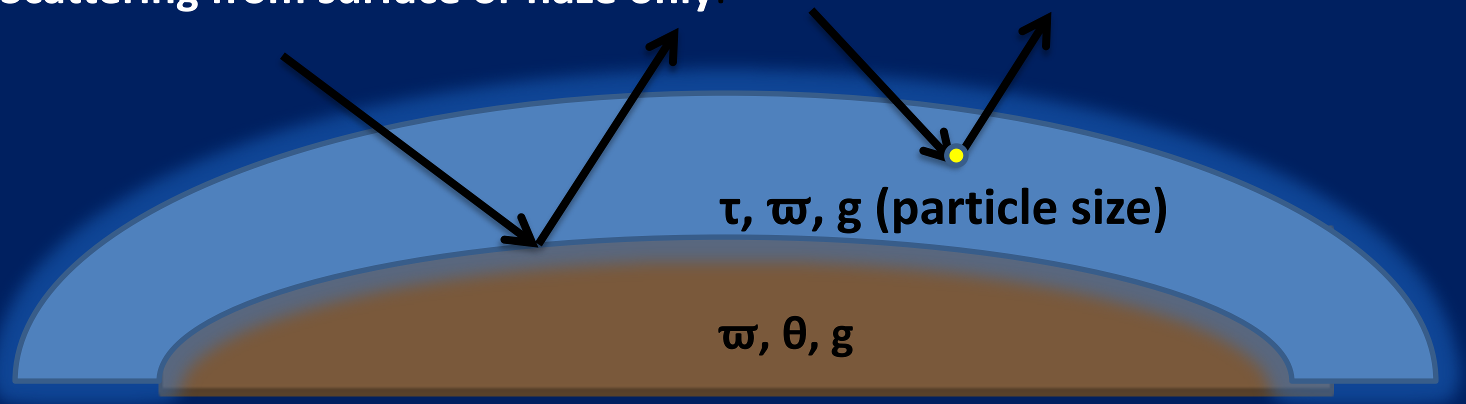
A radiative transfer model for a plane-parallel atmosphere

Hillier et al. (1990, 1991) Triton

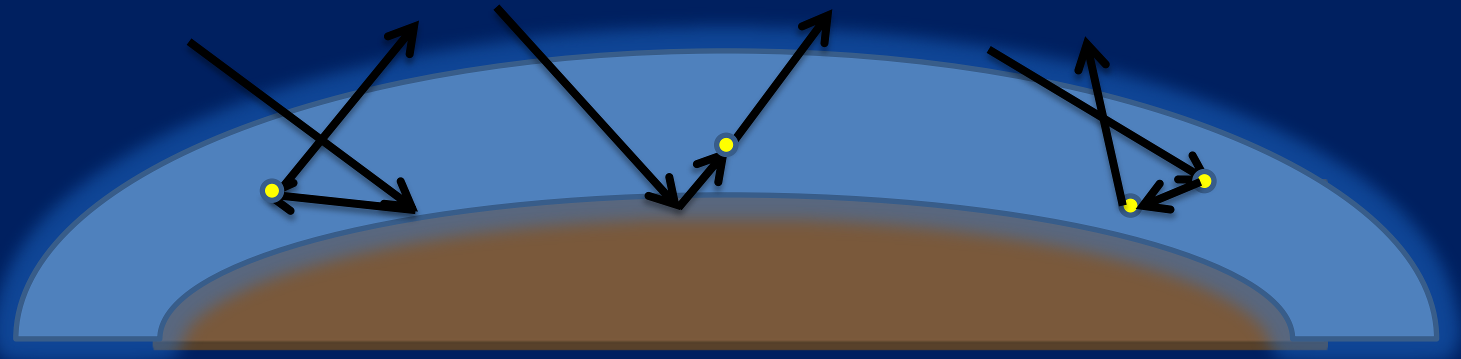
Buratti et al. (2011) Triton Voyager and Ground-based

Based on Chandrasekhar (1960) “The Planetary Problem”

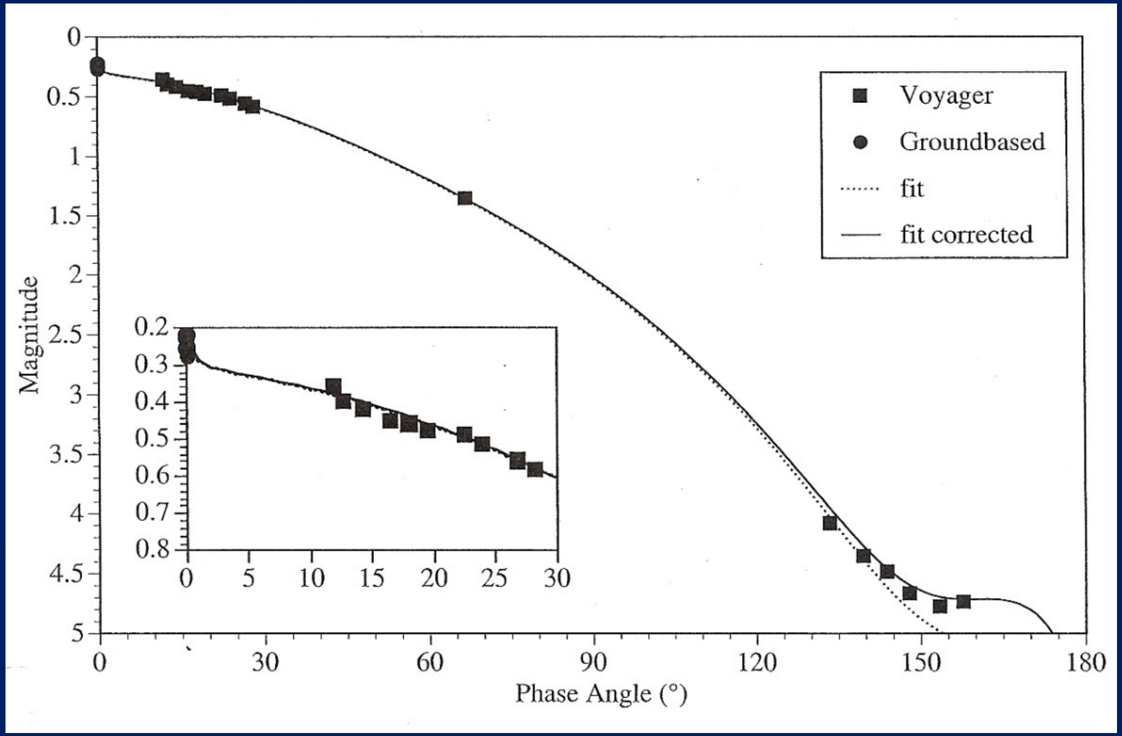
Scattering from surface or haze only:



Scattering by surface and haze, on way down or way out, and twice within the haze



Example of model for Triton



Voyager Green and V filter combined to give ϖ = 0.998; g= -0.32; [θ=14°], (h,B_o = 0.0065; 0.2167; p, q, and A_B also derived.

For the haze, the optical depth τ = 0.03 and the g=0.6 (Buratti et al, 2011).

Ongoing modeling for Pluto

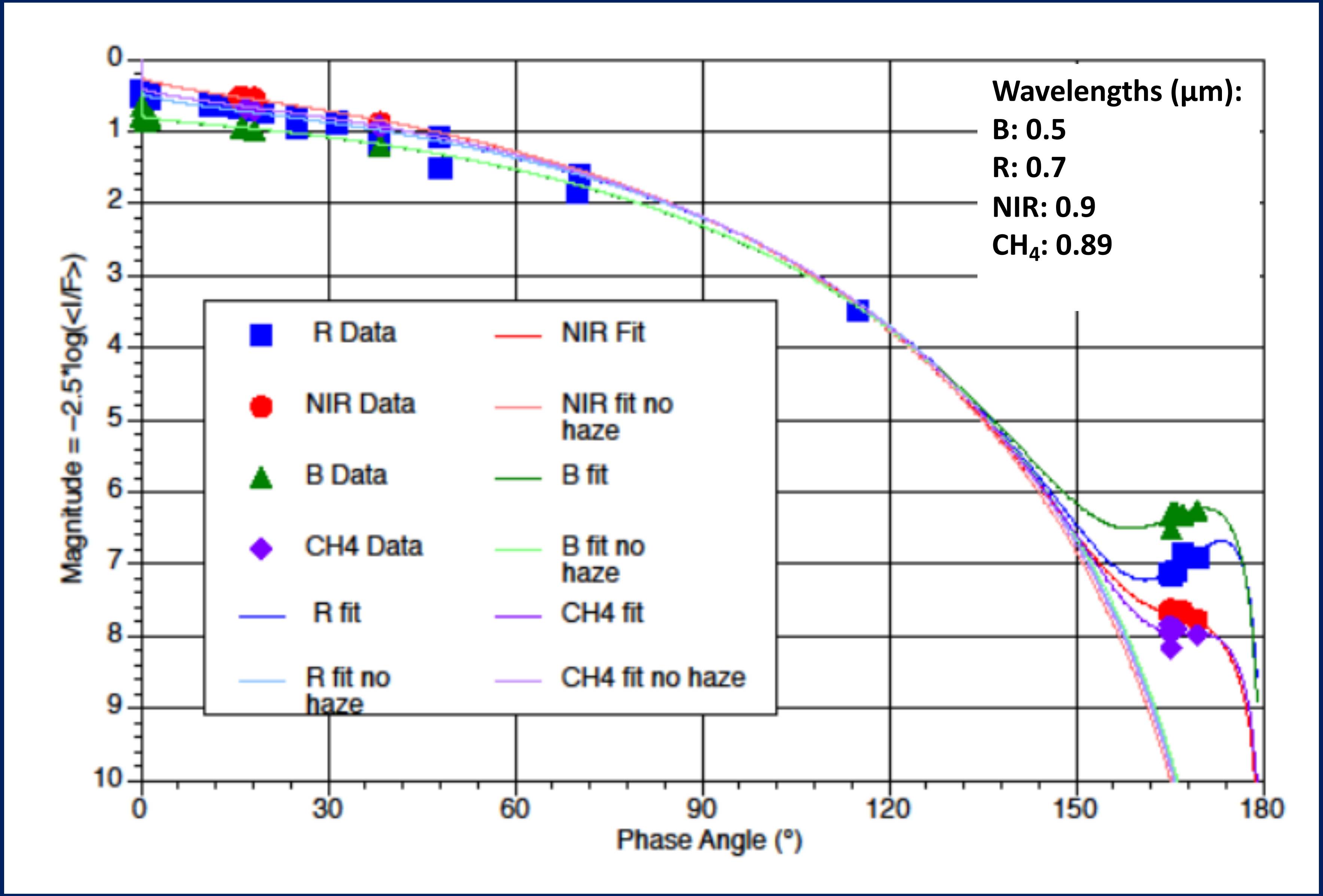
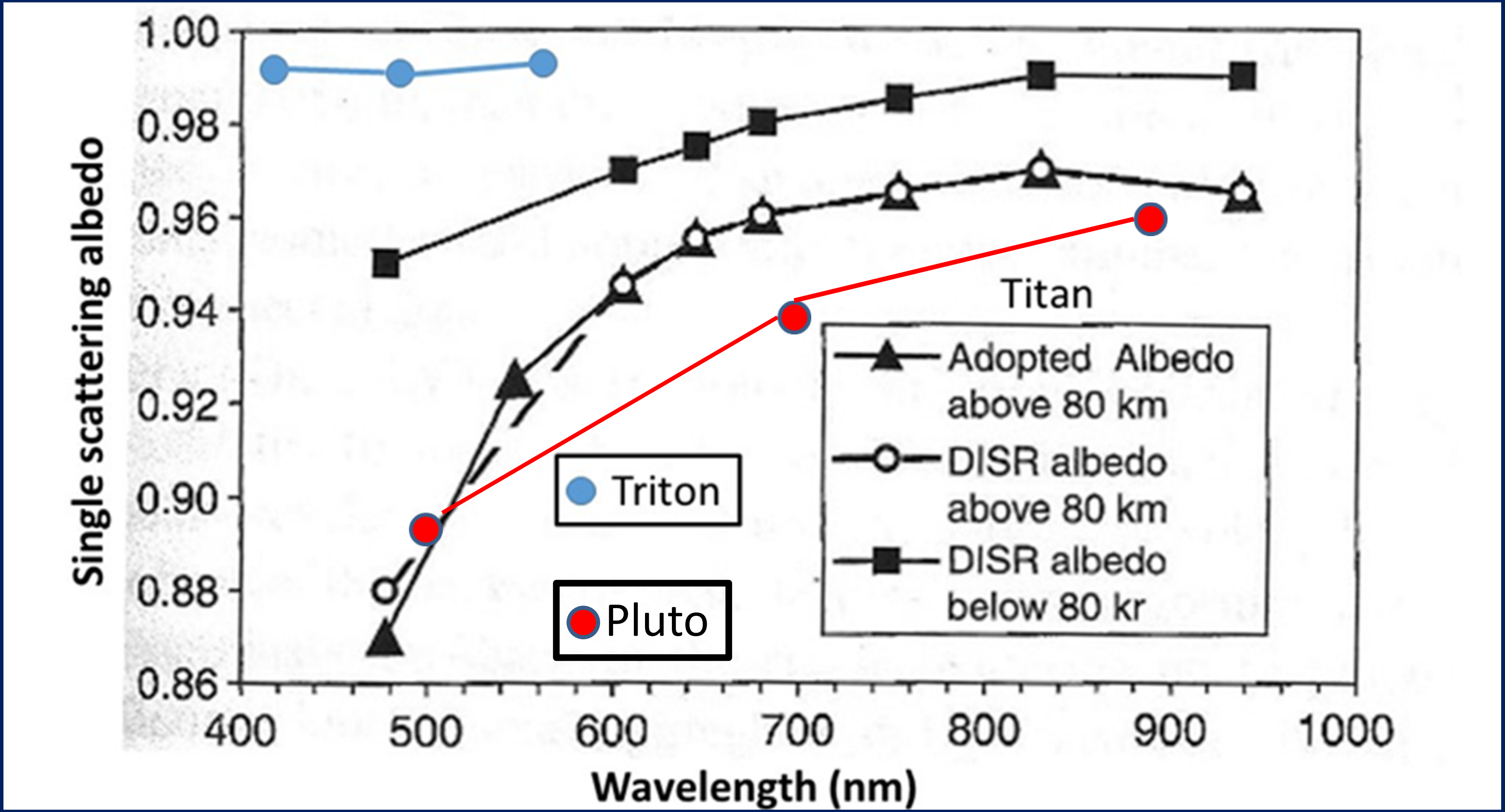


Table – Comparison of surface single scattering albedo (ϖ) and phase function (Henyey-Greenstein g) for the surface and haze; the surface roughness (mean slope angle θ) of surface and optical depth of haze for Titan, Pluto, and Triton

Object	Wave-length	Surface			Haze			Ref.
		ϖ	θ (°)	g	τ	ϖ	g	
Triton	0.41	0.99±0.02	10±0.2	-0.2±0.1	0.06±0.01	0.99±0.02	0.6±0.1	1
	0.47	0.99±0.02	11±0.3	-0.24±0.04	0.06±0.1	0.99±0.02	0.6±0.1	1
	0.56	0.995±0.02	11.5±0.2	-0.23±0.04	0.04±0.01	0.99±0.02	0.6±0.1	1
Titan	0.47		15-30[1]			0.87		2, 3
	0.56					0.93	0.3±0.1[2]	2
	0.61				1.4	0.94	0.3±0.1[2]	2
	0.65				1.2	0.95		
	0.81				1.0	0.97		
	0.89	TBD	TBD	TBD	TBD	0.97	0.4±0.1[2]	2
Pluto	0.50	0.97	(25)	0.04	0.007	0.89	0.82	
	0.61	0.99	(25)					
	0.65	0.99	(25)	-0.006	0.003	0.94	0.86	
	0.81	0.99	(25)					
	0.89	0.99	(25)	-0.05	0.002	0.96	0.80	

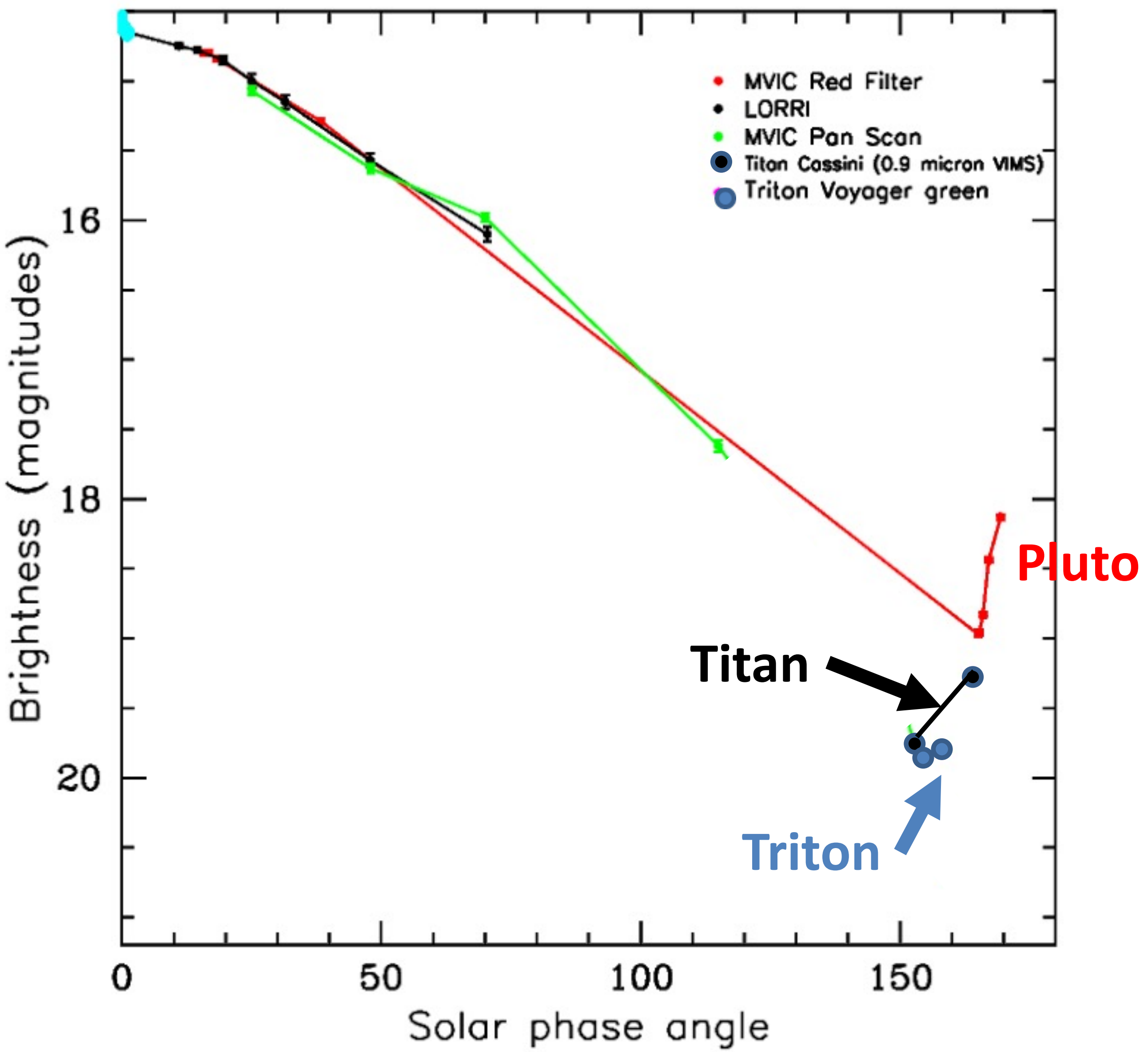
(1) Hillier et al., 1991;
(2) Tomasko and West, 2009;
(3) Buratti et al., 2006.

Spectra of haze (composition)

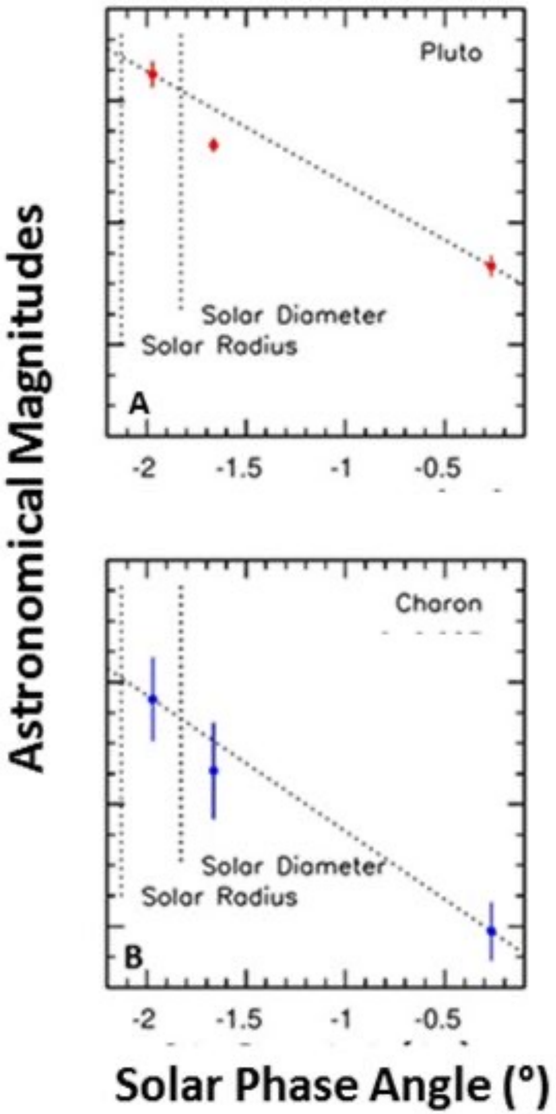


Tomasko and West, 2009; Hillier et al., 1991
Pluto's haze is organics (Gladstone et al., 2016); spectra not yet determined

Comparison of forward-scattering



New Horizons did not do all things



Summary

- Extraordinarily high albedo variegations on Pluto, ranging from 0.08 to ~1. Unit albedo solidifies the connection between very bright surfaces and geologic activity. Charon albedo distribution is more “normal”.
- Photometric model of Charon shows it is much like other water-icy and rocky bodies. It does not appear to be very strongly backscattering.
- Pluto modeling is challenging, but preliminary work shows its haze is reddish like Titan’s and unlike Triton’s. Surface like
- Both bodies have huge opposition surges (ground-based result)